Division of Agricultural Sciences
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TILLAGE AND NITROGEN FOR DRYLAND GRAIN

. . . IN A WINTER RAINFALL CLIMATE

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CALIFORNIA AGRICULTURAL
EXPERIMENT STATION

BULLETIN 805

This bulletin, written as a reference for agronomists and soil scientists,

- describes climate, soil, and cropping systems for dryland agriculture in a winter rainfall climate;
- reports experimental results showing major tillage effects on soil moisture storage, soil nitrification, plant growth, grain quality, and yield;
- reports experimental results showing the wide range in effects of nitrogen fertilization and legume cropping on dryland grain production; and
- discusses soil moisture-nitrogen relations as they are affected by tillage and nitrogen application.

The research reported in this bulletin has been a cooperative effort by the Southwest Branch, Soil and Water Conservation Research Division, Agricultural Research Service, USDA, and the California Agricultural Experiment Station.

AUGUST, 1964

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TILLAGE AND NITROGEN FOR DRYLAND GRAIN

THE FINDINGS

EXPERIMENTS were conducted in southern California over a 15-year period to evaluate tillage and nitrogen fertility in dryland grain production. Field studies involved the prevailing fallow-grain cropping system. Tillage experiments included a study of methods and times of primary fallow tillage. One of the specific objectives was to compare subsurface or stubble-mulch tillage with the more intensive methods, such as moldboard plowing and disking. The duration of the tillage experiments ranged from 6 to 15 years. Nitrogen fertility studies included rate and source variables. Thirty-two nitrogen fertilizer experiments were conducted.

Average rainfall over the 15-year period was approximately 80 per cent of the long-time average, ranging between 9 to 15 inches for the different sites. Most of the soils were formed from granitic alluvium and contained less than 0.1 per cent total nitrogen. In some of these soils (mainly the Placentia and Arlington[2] series), moisture movement was undoubtedly restricted by layers of high bulk density.

Tillage

Grain yield. During a period of less than 10 inches annual rainfall, tillage methods had little or no effect on grain yield in three of four years on an Arlington sandy loam. Moldboard plowing outyielded chiseling and subtilling by nearly 500 pounds of grain per acre in one year. Fall or winter fallow tillage was frequently superior to spring tillage. Application of up to 2 tons of straw per acre on the soil surface when barley was in the seedling stage did not affect yield in two of three years. The 2-ton rate decreased yield one year.

With annual average rainfall of 13 to 14 inches, moldboard plowing averaged 400 and 500 pounds per acre more grain than did disking or subtilling, respectively, on Ramona and Placentia sandy loams. Yields with plowing were also significantly greater when 30 pounds of nitrogen per acre were applied. Average yield increases from nitrogen were larger on disked and subtilled plots, but subtillage with nitrogen averaged more than 300 pounds less than plowing without nitrogen, indicating a greater need for nitrogen with subtillage.

Fallow tillage had little or no effect on grain yield where production was low (average of 1,000 pounds per acre) on an eroded Placentia sandy loam. Nitrogen was not limiting for grain production at this site, although rainfall averaged about 15 inches over a 12-year period. Fall chiseling resulted in significant yield increases over midwinter disking on this soil.

Test weight of grain. Fallow tillage methods—moldboard plowing, disking, and subtilling—usually had little effect on the test weight of grain. Exceptions in two years were lower test weights with plowing and disking.

Crude protein content of grain. Higher crude protein content of grain was obtained with moldboard plowing. An average increase of 3 per cent over other tillage methods was measured for four cropping seasons. Lowest protein levels were obtained when chiseling, rodweeding, or subtilling were the primary fallow tillage methods.

Yield and nitrogen content of straw. On Ramona sandy loam soil with

[1] Submitted for publication November 13, 1963

[2] Tentative soil series.

15 inches average annual rainfall, straw production with plowing was 500 and 600 pounds per acre greater than with disking and subtilling, respectively. Highest nitrogen content of straw usually occurred with plowing. In an experiment where grain yields were not affected by tillage, both yield and nitrogen content of straw were highest with plowing.

Soil nitrates. Soil nitrate accumulation over the fallow period was greatest with moldboard plowing. Increases up to 80 per cent over subtilling and disking were determined in some years. Higher grain yields in some experiments and generally higher crude protein content of grain, higher straw yields, and higher nitrogen contents of straw undoubtedly reflect the greater nitrogen availability with plowing.

Residual effect. Forage production of volunteer barley was significantly greater on plowed than on disked or subtilled plots two years after tillage operations were performed.

Residue reduction. Six months after tillage, 60 per cent of the crop residue remained on the soil surface with subsurface tillage (stubble mulch). Residue remaining on plowed, chiseled, and disked plots amounted to 8, 38, and 46 per cent, respectively.

Soil moisture. Soil moisture storage over the fallow period was 1.56 inches greater with subtilling than with plowing one of four years. No significant difference was measured in other years, and there was no reflection in yield in any of these years.

Nitrogen

Crop response. On low nitrogen soils the practice of fallowing frequently does not insure adequate available nitrogen for dryland grain even under very limited rainfall. Yield increases with applied nitrogen were obtained in 18 of 32 experiments over a 15-year period. Increases exceeded 200 pounds in one-third of the experiments.

Yield decreases with the application of nitrogen occurred in a few experiments. Observations of the crop indicated greater moisture stress toward the end of the growing season on plots with more available nitrogen.

Rate of application. Where nitrogen was needed, 30 to 40 pounds per acre (applied before planting) were optimum for dryland grain after fallow. Lower rates reduced the probability of yield increase and higher rates increased the probability of yield decreases.

Crude protein and test weight. Applied nitrogen usually increased the crude protein content of grain, but soil type and growing season were modifying factors. Nitrogen reduced test weight in a few instances.

Straw production. Consistent and frequently large increases in straw yield (up to 800 pounds per acre) were obtained from applying 30 to 40 pounds of nitrogen. Increases in straw yield occurred even when grain yields were decreased or not affected.

Residual effect. Air-dry forage yields of barley were increased over 1,000 pounds per acre by the residual effect of 30 pounds of nitrogen applied the relatively dry previous year for a grain crop.

Phosphorus. Grain yield response to phosphate fertilizer was obtained in 2 of 14 field experiments. In both cases, yields were increased only when nitrogen fertilizer was also applied.

Legume cover crop. Over an 11-year period, 30 pounds of nitrogen usually produced higher grain yields than a purple vetch cover crop between barley crops. Under the low rainfall of southern California, nitrogen in the tops of winter legumes frequently has not exceeded 50 pounds per acre.

Dryland farming is generally characterized as crop production in areas where lack of moisture is the major limiting factor. Nonirrigated, arable lands receiving an average of 8 to 20 inches of precipitation are considered to be dry-farmed. More than 3 million acres of cropland in California are in dryland agriculture. Approximately 400,000 acres are dry-farmed in southern California. A major portion of this land is unsuitable for irrigation because of rolling topography, shallow soil, or no readily accessible source of water for irrigation.

Climate

Annual rainfall distribution and other climatic factors, principally temperature and solar radiation, determine crop-growing conditions in a particular area. The climate of California is frequently described as a dry, mild winter or Mediterranean type. Taylor (1960) has classified dryland climates into six types. His climatic Type I most nearly represents the California climate: "Warm, dry growing weather with precipitation occurring mostly as snow and rain during a mild winter season such as occurs in the intermountain region of the western

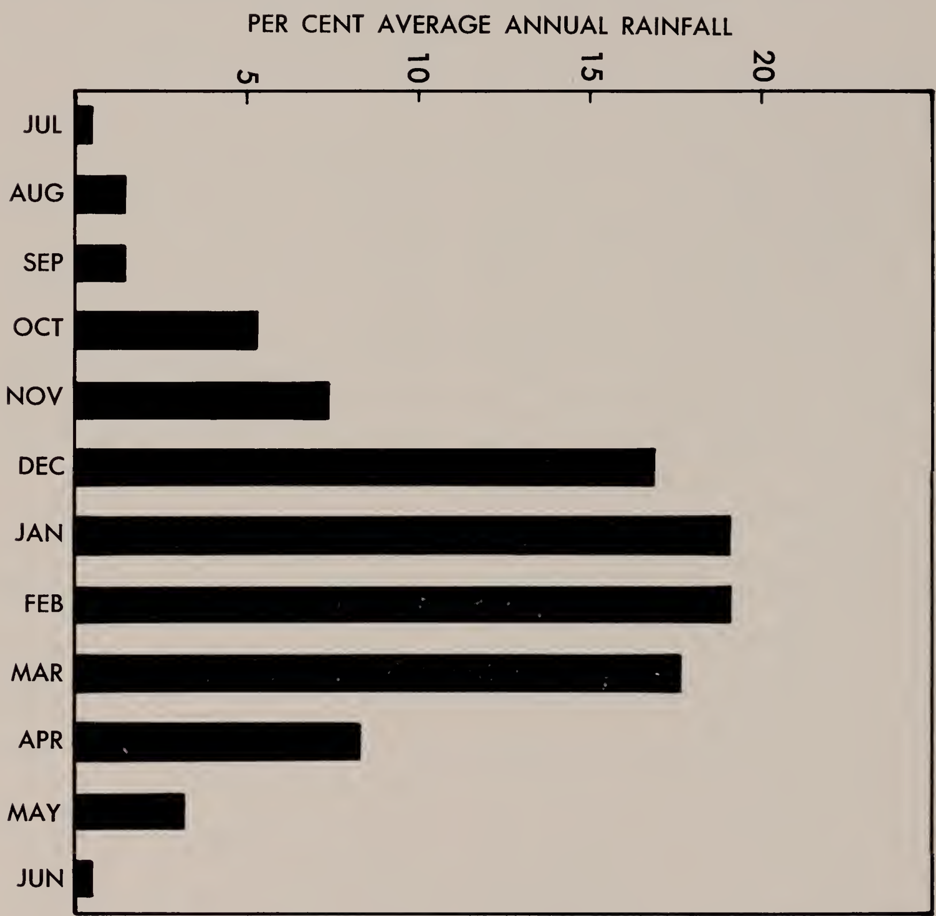

Figure 1. Monthly Rainfall as a Percentage of the Average Annual Amount for an 80-year Period (1880–1960), Riverside, California.

United States." Except for the northernmost counties, snowfall is not significant in California dryland agriculture, and effective rainfall is received during a relatively short period of the year, in contrast to other intermountain areas. Significant amounts of rainfall usually occur only in the winter and early spring months. At Riverside, more than 72 per cent of the annual average has been recorded during the months of December, January, February, and March (figure 1). Negligible amounts of moisture are received between June and September. An analysis of 65 years of Los Angeles rainfall records by Donnelly (1943) shows that years of below-average rainfall exceed those of above-average. Mean rainfall was 1.6 inches greater than the median rainfall.

Field data on dryland soil management discussed in this bulletin were obtained from 1945 through 1960, a period of below-average rainfall. The long-time average of 11.06 inches at Riverside (determined by the U. S. Weather Bureau for the 1880–1960 period) was exceeded in only three years, and the average for 1945–60 was 82 per cent of the 80-year average (table 1). A review of rainfall data from several locations in southern California revealed that while different locations consistently receive more or less amounts than others, seasonal distribution is similar.

Evaporation from a free-water surface is directly related to moisture use by plants. Over the 35-year period of 1925–60 at Riverside, an average of nearly 65 inches evaporated annually (table 2). The amounts for November, December, January, and February are relatively low. Evaporative potential increases in March and continues to increase, reaching a peak in July, when an average of 9.21 inches evaporated from a free-water surface. Beginning with September, the potential for evapotranspiration markedly decreases during the remainder of the year.

The growing season for dryland crops in a Mediterranean-type climate is determined by the yearly rainfall distribution. Frosts rarely affect the length of growing seasons, in contrast to the continental dryland climate which prevails in the Great Plains. The length of any one season in winter rainfall areas is largely limited by the earliness and lateness of effective rainfall. Depending on local conditions, dryland cereals are usually planted between November 15 and January 15 and do not mature until late June. During the last 12 weeks of the growing season, the probability of rainfall decreases and the probability of greater moisture use through evapotranspiration increases. Crops frequently show moisture stress during this period, the level of grain yield being determined by the amount of late rainfall or available moisture stored in the soil.

During the recent 15-year dry period, poor distribution as well as lower amounts of rainfall have decreased production. Except for the 1951–52, 1953–54, and 1957–58 seasons, little or no significant moisture has been received in the spring (table 1). The data suggest that low-rainfall years have shorter seasons of effective rainfall. Higher average evaporation from a free-water surface is also associated with the low-rainfall period (table 2).

Crops and Cropping Systems

Small grains, because of their characteristic growing season and drouth tolerance, are the best adapted crops for dryland agriculture. Spring varieties are grown under the mild winter climatic conditions. The dryland acreage of small grain exceeds 2 million acres in California each year. Barley and wheat predominate, with barley occupying twice the acreage of wheat. Oats are grown on a relatively small dryland acreage. Small grains contribute markedly to the California agricultural economy through the feed industry, brewing industry, and the

Table 1. Monthly and Annual Precipitation at Riverside, 1945–60
(U. S. Weather Bureau)

Year*	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual
							inches						
1945–46	.02	1.01	.07	.41	.21	4.16	.08	.76	2.08	.64	.04	.00	9.48
1946–47	.05	.00	.15	.51	4.41	1.56	.12	.26	.91	.25	.05	.05	8.42
1947–48	.00	T	.03	.09	.03	1.78	.06	1.76	1.19	.75	.17	.30	6.16
1948–49	.00	.00	.00	.93	T	2.20	2.78	1.08	.73	T	.57	.00	8.29
1949–50	.00	.00	.00	.10	1.09	1.46	1.72	1.80	.65	.63	.08	T	7.53
1950–51	.00	.00	.03	.00	1.11	.03	1.45	.64	.48	1.55	.29	.00	5.58
1951–52	T	.02	.18	.52	.44†	5.49	5.08	.24	3.88	1.61	.01	.00	17.47
1952–53	.21	T	.51	.00	2.84	2.74	.69	.24	.84	1.45	.06	T	9.58
1953–54	.00	.07	.00	T	2.21	1.09	3.75	1.80	2.59	.05	.00	.00	11.56
1954–55	.10	T	.00	.00	2.27	.72	2.92	1.07	.22	.37	1.11	.00	8.78
1955–56	.00	T	.00	.00	.88	.49	4.34	.29	.00	1.61	.22	.00	7.83
1956–57	1.26	.00	.00	.19	.00	.20	4.12	.80	.93	1.03	1.06	.14	9.73
1957–58	.04	.00	.00	1.42	.43	2.06	1.10	3.17	3.58	2.89	.24	.07	15.00
1958–59	.00	.45	.26	.25	.06	.00	.71	2.41	.00	.18	.01	.00	4.33
1959–60	T	.02	.02	.00	.50	1.06	2.03	2.05	.29	1.05	.08	T	7.10
15-yr. Avg.	.11	.10	.08	.29	1.10	1.67	2.06	1.23	1.22	.94	.27	.04	9.11
80-yr. Avg., 1880–1960	.04	.15	.16	.58	.81	1.86	2.11	2.11	1.95	.91	.34	.04	11.06

* Rainfall year beginning July 1.
† Estimated from nearby locations.

Table 2. Average Monthly and Annual Evaporation from a Free-Water Surface, University of California, Riverside

Period	Evaporation, inches												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1925–60	2.58	2.86	4.39	5.36	6.85	7.69	9.21	8.58	6.70	4.75	3.47	2.44	64.9
1946–60	2.43	2.94	4.48	5.42	6.65	7.96	9.35	8.58	7.00	4.84	3.32	2.63	65.6

baking and milling industries. Oil crops, mainly safflower, and some forage crops are now being more widely grown on nonirrigated land.

The prevailing cropping system for dryland grains alternates fallow with cropping in a two-year cycle. The chief purpose of fallow has been moisture conservation. Mathews (1951) considers fallowing necessary for crop production when annual precipitation is less than 15 inches. The practice may be profitably used in certain areas where rainfall exceeds 20 inches.

Another important purpose of fallow is nitrate accumulation in the soil. Littlejohn (1956) found that fallow increased soluble nitrogen five to six times over recent cropping in a winter rainfall area. Staple (1960) recently reported that fallow grain crops have not responded to nitrogen fertilizer in Canada and the United States, presumably because fallow makes sufficient nitrates available.

Soils

A large part of the field research was conducted on sandy loam soils developed from granitic alluvium. Major soil series were Ramona, Placentia, and Arlington. The Ramona sandy loam is a well-drained Noncalcic Brown soil occurring on gentle slopes. It has a neutral to slightly acid A-horizon extending to a depth of about 15 inches. The B-horizon has a sandy clay loam texture and is neutral in reaction. The mildly alkaline, sandy loam C-horizon occurs at about 50 inches. The chief difference between the Ramona and Placentia sandy loams is the strongly developed clayey layer in the B-horizon of the latter. This compact layer restricts root development and internal drainage.

Tillage experiments at Riverside were located on a soil which has a weakly cemented layer in the profile. This layer occurs at a depth of from 24 to 42 inches and varies in thickness from 20 to 36 inches. The soil has less clay in the B-horizon than does the Ramona and was formerly mapped as Greenfield. The Soil Conservation Service is currently considering the establishment of a new series for this soil, which is tentatively designated as Arlington.

Most of the California dryland soils have been formed under semiarid conditions. Soil organic matter contents are characteristically low. Soil samples from several experimental sites where dryland cropping has been practiced were analyzed for organic carbon content by the chromic acid wet digestion method. Samples of uncropped or virgin soil adjacent to the cropped areas were obtained at two locations. All cropped soils contained less than 1 per cent organic matter in the surface 6 inches, and less than 0.65 per cent at the 18- to 24-inch depth (table 3).

The data indicate that after from 50 to 70 years of grain cropping, mostly in the alternate fallow-grain system, from 30 to 40 per cent of the organic matter has been lost in the surface 6 inches. Smaller losses occurred below the 6-inch depth.

Much dryland agriculture in California is located on lands with relatively steep slopes and on soils with moderate to low infiltration rates. As a consequence, soil erosion and runoff have occurred with individual storms even though annual

Table 3. ORGANIC MATTER CONTENT OF SOILS CROPPED UNDER DRYLAND CONDITIONS IN SOUTHERN CALIFORNIA, 1952

Location	Soil type	Slope	History	Organic matter*			
				0–6″	6–12″	12–18″	18–24″
		per cent		*per cent*			
Beaumont..........	Ramona sandy loam	3	Cropped 70 yr	0.91	0.76	0.69	0.64
			Virgin	1.31	0.99	0.82	0.76
Beaumont..........	Placentia sandy loam	9	Cropped 70 yr	0.87	0.68	0.49	0.45
			Virgin	1.48	0.82	0.54	0.42
Riverside...........	Arlington† sandy loam	3	Cropped 50 yr	0.90	0.51	0.34	0.36
Beaumont..........	Placentia sandy loam	4	Cropped 75 yr	0.96	0.84	0.72	0.65

* Organic carbon X 1.7; average of 54 soil samples on cropped soils; minimum of 6 samples on virgin soil.
† Tentative soil series.

rainfall has been low. Nearly every winter the effect of erosion by water is evident on bare fallow or seeded cropland.

Sustained high wind velocities have caused soil erosion in certain areas of California. In addition to the loss of topsoil, the abrasive action of drifting soil particles may have a damaging effect on crop plants.

TILLAGE

FIELD RESEARCH in other areas of the United States has shown that crop residues on the soil surface control runoff, water erosion, and wind erosion. In eastern Nebraska, Duley and Russel (1939) reported that 2 tons of straw per acre on the surface conserved 3.6 inches more water in the soil than did plowing the straw in. In their summary of stubble-mulch research in the western states, Zingg and Whitfield (1957) referred to soil losses on plowed and mulched land at Lincoln, Nebraska, and Pullman, Washington. At Lincoln, average annual amounts of erosion were 1.26 and 6.02 tons of soil per acre for the mulched and plowed surfaces, respectively. At Pullman, 3.63 and 17.93 tons per acre were lost with mulching and plowing, respectively. Approximately 1 ton of straw per acre comprised the mulch at both locations.

In early wind erosion studies, Chepil (1944) observed that crop residues on the soil surface markedly reduced wind velocity and soil erosion. More recent work in Kansas (Zingg and Whitfield, 1957) indicated that from 500 to 2,000 pounds of anchored surface residues, depending on soil properties, would stabilize the surface against wind erosion.

The major objectives of tillage experiments reported here were (1) to determine the magnitude of tillage effects on crop yield, and (2) to ascertain the soil factors which may be responsible for the tillage effects obtained. Nitrogen analyses of soil and crop were included. Moisture conditions have been characterized by monthly rainfall data and some soil moisture data. Surface residue reduction was measured for certain tillage methods.

Tillage experiments were conducted at several locations in southern California from 1945 to 1960. The use of three implements for the initial and major fallow tillage operation was common to all experiments. These implements and the approximate depth of operation were moldboard plow, 8 to 10 inches; disk, 4

to 6 inches; and subtiller, 4 to 5 inches. The latter implement is frequently referred to as a sweeps machine. In these experiments, the Noble blade was chosen to represent subsurface tillage equipment. Throughout the tillage studies, all operations were completed under the direction of one of the authors and with equipment maintained only for this purpose. Operations necessary for weed control and seedbed preparation could be considered minimal when compared to the number of operations commonly used in dry-farmed areas.

Plot sizes ranged from .05 to .5 acre, depending on the experiment. Approximately 70 pounds of barley and 50 pounds of wheat per acre were drilled in a 7-inch spacing. Entire plots were harvested for yield. Crop varieties used in field studies were Club Mariout barley, Atlas barley, and Ramona wheat.

Grain Yield

Experiment No. 1. Twelve different tillage methods were compared on an Arlington sandy loam soil in an experiment initiated in 1949 at Riverside. Plots were .05 acre in size. Treatments were replicated four times and alternated between two adjacent plot areas to provide for yields each year under the fallow-crop system. Four tillage methods were used in the fall prior to the fallow rainfall season, one method during the fallow winter period, and six methods in the spring. Depths of tillage were as follows: subsoiler, 12 to 18 inches; chisel and moldboard plow, 6 to 8 inches; disk and disk plow, 4 to 6 inches; and subtiller and rodweeder, 3 to 4 inches. Except for the nontillage plots, where weeds were sprayed, uniform shallow tillage was performed with the rodweeder for subsequent weed control.

Statistical analysis of the yield data included use of the Duncan's multiple range test for determining the significance of differences. Over the four-year

Table 4. Effect of Fallow Tillage Methods on Barley Grain Yield in a Fallow-Barley Cropping System, Arlington Sandy Loam Soil, Riverside

Year*	No tillage†	Fall tillage				Winter	Spring tillage						Avg.
		Subsoiler	Chisel	Subtiller	Disk	Disk	Chisel	Subtiller	Rodweeder	Moldboard plow	Disk plow	Disk	
	pounds per acre												
1950	1175	896	858	911	776	842	650	709	788	661	636	715	801
1952	1490	1517	1574	1454	1529	1575	1600	1495	1504	1420	1481	1659	1525
1953	853	1125	1038	1168	1108	955	610	875	928	725	435	618	870
1954	1278	1241	1068	1116	1278	1456	964	941	958	1371	1466	1091	1185
Avg.	1196	1195	1134	1162	1173	1207	956	1005	1044	1044	1004	1021	....

* No grain production in 1951.
† Weed control by spraying.

period, yields with no tillage, winter disking, and several fall tillage methods were significantly higher than with any of the spring tillage methods (table 4). Annual average yields reflect the differences in growing-season rainfall (table 1). Except for the difference between 1950 and 1953, annual average yield differences were statistically significant.

Statistical analysis also revealed a significant interaction of tillage method and years. Fall tillage operations resulted in consistently higher average yields than spring tillage for the 1950 crop. No fallow tillage resulted in significantly higher grain yield than any other tillage treatment. The yield with fall subtilling also was significantly higher than that for disk plowing in the spring. In 1952, the highest rainfall year in this study (table 1), none of the yield differences were significant. All fall and winter tillage and spring subtilling and rodweeding were superior to the intensive spring methods in 1953. Plowing, disking, and chiseling in the spring of the fallow year may have resulted in more soil moisture loss after a favorable season for moisture storage. Except for plowing, spring fallow tillage methods were low for 1954 crop yields. Yields with spring subtilling, rodweeding, and chiseling were significantly lower than fall disking and all higher yielding methods.

In summary, fall or winter fallow tillage was frequently superior to spring tillage, particularly during the crop years when rainfall was the lowest—1950 and 1953. No tillage with chemical weed control usually was equivalent to or better than other methods except when a dry crop year followed a relatively high-rainfall fallow year.

Experiment No. 2. Three tillage methods were compared near Beaumont, an area of higher rainfall than that in Experiment No. 1. The long-time average rainfall at Beaumont exceeds 18 inches. As in southern California generally, rainfall during the period 1945–60 was approximately 80 per cent of the long-time average. At the Haskell Ranch experimental site, moldboard plowing nearly always produced higher yields than disking or subtilling (table 5). The average increase on check plots for three years and two soils was 453 and 507 pounds per acre over disking and subtilling, respectively. Statistical analysis showed that yield increases with plowing on nonfertilized plots in 1948 were highly significant when compared with both disking and subtilling. In 1950, plowing was significantly better than disking, and disking was significantly better than subtilling. Again in 1952, yields with plowing were significantly higher than with disking or subtilling.

Thirty pounds of nitrogen as ammonium sulfate, applied before barley seeding, increased over-all average yields with all tillage methods. In 1948, on Ramona sandy loam, these increases were statistically significant on disked and subtilled plots. Nitrogen significantly increased yields with plowing and disking on the Placentia sandy loam. Yield differences in 1950 were not significant, although there were increases with nitrogen on the Ramona soil. Consistent and greatest yield increases were obtained with nitrogen on all tillage methods in 1952.

In summary, yields were significantly higher from plowing than from disking or subtilling with and without nitrogen. Average yield increases from nitrogen were larger on disked and subtilled plots than on plowed plots. The application of 30 pounds of nitrogen failed to make disking and subtilling comparable to plowing. Subtillage with nitrogen averaged more than 300 pounds less than plowing without nitrogen.

Experiment No. 3. An experiment similar to Experiment No. 2 was conducted at the Houston Ranch near Beaumont on an eroded Placentia soil with grain cropping in the odd-numbered years. Barley yields for six crops are

Table 5. Effect of Tillage Method* on Barley Grain Production after Fallow Under Variable Nitrogen Fertility, Haskell Ranch, Beaumont

Soil	Year	Rain-fall†	Plow		Disk		Subtiller	
			Check	30 lb N/A	Check	30 lb N/A	Check	30 lb N/A
		inches	*pounds per acre*					
Ramona sandy loam..........	1947	15.1						
	1948	9.7	1459	1589	1236	1646	1203	1583
	1949	11.4						
	1950	11.8	3638	3180	2434	3004	2282	2630
	1951	8.8						
	1952	22.8	1411	1760	900	1456	997	1566
Avg......................		13.3	2169	2178	1523	2035	1494	1926
Placentia sandy loam.........	1948		1205	1777	1018	1420	1203	870
	1950		2821	2790	2337	2580	1988	1837
	1952		1040	1446	935	1344	860	1184
Avg......................			1689	2004	1430	1781	1350	1297
Soils avg.................			1929	2091	1476	1908	1422	1612

* Tillage operations between March 15 and April 7.
† For 12 months preceding July 1 of year listed.

presented in table 6. Yields were low for the rainfall received at this experimental site, and neither tillage nor nitrogen had a significant effect. Although small differences in yield with tillage method were measured several years, none of the methods was consistently better than the others.

Experiment No. 4. Midwinter disking, fall chiseling, and no tillage were compared on the Placentia soil at the site of Experiment No. 3. This soil has a bulk density of 1.6 at a depth of 18 inches and is almost impenetrable to sampling in the dry state below that depth. An average yield increase of 16 per cent for fall chiseling over midwinter disking was measured (table 7). Improved moisture penetration with fall chiseling probably accounts for the difference. Volunteer barley and weeds on the no-tillage plots may have increased infiltration slightly over disking, which frequently increases runoff.

Yield results indicate that soil moisture was limiting in Experiments 3 and 4 on the Placentia soil at the Houston Ranch. Poor physical characteristics of the soil could have been a greater factor than the amount of rainfall. Recent studies also indicate that lack of available phosphorus may have limited yields.

Experiment No. 5. To determine if the crop residue left on the surface by subsurface tillage was responsible for reduced grain yields, a range of straw applications was made to plots of barley in the early seedling stage at Riverside. Four rates of straw application and a check were replicated four times.

Amounts of available soil moisture at planting were negligible every year. Soil nitrates were relatively high at planting for the 1952 and 1953 crops, averaging 13 and 19 ppm in the surface six inches, respectively. Treatments in these years were on different but adjacent plots. The 1952 and 1954 plots were the same. At planting time for the 1954 crop, surface soil nitrates averaged 5 ppm. There was, however, no effect of the straw applied two years previously on the amount of nitrates present before planting the 1954 crop. Subsurface tillage was used in the

Table 6. Effect of Tillage Method on Barley Grain Production under Variable Nitrogen Fertility,* Placentia Sandy Loam, Houston Ranch, Beaumont

Year	Rainfall†	Plow		Disk		Subtiller	
		Check	30 lb N/A	Check	30 lb N/A	Check	30 lb N/A
	inches	*pounds per acre*					
1949	11.4	576	522	530	459	588	510
1950	11.9						
1951	8.8	900	740	887	699	932	842
1952	23.3						
1953	13.6	1096	1334	996	1014	1080	1210
1954	16.9						
1955	11.6	1486	1566	1356	1354	1349	1485
1956	11.5						
1957	12.7	354	479	380	492	378	499
1958	24.2						
1959	7.6	1052	984	1320	1256	1373	1465
Avg	14.0	911	938	911	879	950	1002

* Average of 2 plot yields.
† For 12 months preceding July 1 of year listed.

Table 7. The Effect of Time and Method of Fallow Tillage on Barley Grain Yields,* Placentia Sandy Loam, Houston Ranch, Beaumont

Year	Tillage		
	No tillage†	Midwinter disk‡	Fall chisel§
	pounds per acre		
1949	692	638	707
1951	851	770	1050
1953	957	728	893
1955	1266	1208	1386
1957	370	285	395
1959	1281	1175	1292
Avg.‖	903	801	954

* Average of 3 plot yields.
† No tillage until April of fallow year.
‡ Disking in January of fallow year.
§ Chiseling to a depth of 6 to 8 inches in November of fallow year.
‖ Difference between means for fall chiseling and midwinter disking is statistically significant.

1953 fallow operations, and straw remained on the surface from the 2,000- and 4,000-pound applications made the previous year.

In two of the three years, straw ranging up to 4,000 pounds per acre had no effect on barley yields (table 8). A yield

Table 8. Effect of Straw Mulch on Barley Production after Fallow, Riverside

Year	No straw	500 lb/A	1000 lb/A	2000 lb/A	4000 lb/A
	pounds per acre				
1952	975	885	937	974	993
1953	739	746	823	857	826
1954*	404	454	444	333	283

* Difference between no straw and 4000 lb/A is statistically significant at the 1 per cent level.

depression was obtained with the 1- and 2-ton straw applications in 1954. The cumulative effect of the 1952 and 1954 straw applications may have been a significant factor in 1954 yield depression.

Grain Quality

The test weight generally is the criterion for quality when grain is marketed for feed. A high test weight indicates plump, rounded grain, in contrast to wrinkled or shriveled grain. Tillage method can affect the test weight of dryland grain, as shown in table 9. In 1952 at Riverside, plowing decreased test weight significantly when compared to

Table 9. EFFECT OF TILLAGE METHOD* ON TEST WEIGHT OF BARLEY GRAIN, RIVERSIDE

Year	No tillage	Fall tillage				Winter	Spring tillage					
		Sub-soiler	Chisel	Sub-tiller	Disk	Disk	Chisel	Sub-tiller	Rod-weeder	Disk	Disk plow	Mold-board plow
	pounds per bushel											
1952†.......	43.5	42.2	41.4	43.6	42.8	40.4	42.9	44.1	43.2	40.0	40.7	37.8
1953........	40.3	36.0	34.8	37.5	38.8	36.2	37.0	38.2	36.5	40.0	40.5	39.2
1954†.......	45.1	43.2	44.2	42.8	42.8	40.8	43.2	45.5	44.5	44.9	43.0	40.2

* All fall- and winter-tilled plots were subtilled in the spring. Final tillage on all but spring-subtilled plots was rodweeding. Spring-subtilled plots were subtilled a second time.
† Analysis of variance by years showed highly significant test weight differences in 1952 and 1954 and no significant difference in 1953. In 1952, $LSD_{.05}$ = 2.2 lb/bu, and $LSD_{.01}$ = 2.9 lb/bu; in 1954, $LSD_{.05}$ = 1.9 lb/bu, and $LSD_{.01}$= 2.6 lb/bu.

10 other fallow tillage methods. Winter disking also depressed test weight significantly in 1954, but differences in 1953 were not significant. The subsurface tillage treatments produced the highest test weights both in 1952 and 1954, although grain yields were among the lowest (table 4).

At Beaumont, on Placentia soil, test weights for three crop seasons did not differ more than 2 pounds for plowing, disking, and subtilling.

Crude protein content of small grains is also an important criterion of quality and frequently reflects nitrogen availability to the crop. Data obtained at Riverside illustrate effects of primary tillage methods performed during the fallow year on protein content of barley grain produced the following season (table 10). Moldboard plowing in the spring increased protein content about 3 per cent over no tillage, subtilling, and other fall tillage methods. Winter disking and disk-plowing in the spring also increased protein content. Lowest levels of crude protein, between 10.5 and 11.5 per cent, were obtained with chiseling, rodweeding, and subtilling. A higher protein content of grain with more intensive tillage may reflect a greater nitrogen availability and/or more shriveled kernels, the latter being indicated by test weights (table 9).

Straw Production

Straw yields are an important consideration in these tillage and nitrogen studies because the value of tillage for surface residue management depends to a degree on the amount of straw produced with these methods, and straw production frequently reflects the availability of soil nitrogen more than does grain production. On Ramona sandy loam near Beaumont, average straw production in 1950 was 500 and 600 pounds per acre greater with plowing than with disking and subtilling, respectively (table 11). Grain yield response to nitrogen in 1950 for this location is shown in table 5. On the more sloping land, disking resulted in much greater straw production than subtilling. The potential for increased straw production with an increased nitrogen supply is illustrated by the 1946 results when 30 pounds of nitrogen markedly increased straw yields with all tillage methods.

On the Placentia sandy loam near Beaumont, the average straw production for the six crop years was similar for the three tillage methods (table 12). A consideration of individual years reveals marked differences, however. Straw yields in 1951, 1953, and 1955 were considerably higher in plowed plots. This is in contrast to the grain yields, which

Table 10. Effect of Fallow Tillage Methods on Crude Protein Percentage* of Barley Grain in a Fallow-Barley Cropping System, Riverside

Year	No tillage	Fall tillage: Subsoiler	Fall tillage: Chisel	Fall tillage: Subtiller	Fall tillage: Disk	Winter: Disk	Spring tillage: Chisel	Spring tillage: Subtiller	Spring tillage: Rodweeder	Spring tillage: Moldboard plow	Spring tillage: Disk plow	Spring tillage: Disk	Avg.
							per cent						
1952...........	9.88	9.62	9.75	9.62	10.38	10.44	9.88	9.75	9.75	13.69	11.31	9.75	10.32
1953...........	13.00	14.00	14.06	13.38	13.06	15.88	15.62	14.06	15.06	17.25	16.69	16.19	14.85
1954...........	8.44	8.62	9.06	9.56	9.56	9.81	8.56	8.69	8.56	10.31	8.81	9.06	9.09
Avg........	10.83	10.75	10.96	10.85	11.00	12.04	11.35	10.83	11.12	13.75	12.27	11.67	....

* Average of 4 replications.

differed only slightly with tillage method (table 6).

The foregoing data show that subsurface tillage, which leaves more residue on the soil surface during the fallow season, is not in itself conducive to high residue production.

Nitrogen Content of Straw

Nitrogen content of barley straw was determined in two of the tillage experiments as a means for assessing nitrogen availability with different tillage methods. At the Placentia sandy loam site on the Houston Ranch, the nitrogen content of straw was higher with plowing two of four years than with disking or subtilling (table 13). No appreciable differences between tillage methods occurred in two of the years. Thirty pounds of applied nitrogen consistently increased nitrogen content of straw with all tillage methods. The nitrogen level with subtillage remained lower than that for plowing and disking with the nitrogen addition. Grain yields in this experiment (table 6) did not reflect tillage differences, while straw yields showed differences in some years (table 12).

In another experiment at the same site, straw was analyzed from plots fall chiseled and winter disked (table 14). Again, the more intensive tillage, even though it was performed one year before the crop was planted, resulted in the highest nitrogen content of straw. In this experiment, fall chiseling increased grain yields significantly over midwinter disking (table 7). Spring subtillage of all plots may account for the over-all lower nitrogen levels in the straw in this experiment, as compared to plowing and disking in the previous experiment.

Forage Yield of Volunteer Barley

Forage production of volunteer barley two years after different primary tillage methods had been used was determined

Table 11. EFFECT OF TILLAGE METHOD ON BARLEY STRAW PRODUCTION WITH AND WITHOUT NITROGEN,* RAMONA SANDY LOAM, BEAUMONT

Year	Plow		Disk		Subtiller	
	No N	30 lb N/A	No N	30 lb N/A	No N	30 lb N/A
	pounds per acre					
1946†	2570	3220	2630	3380	2470	2780
1950†	1681	1600	826	1275	944	956
1950‡	1531	1562	1425	1312	1082	1094
Avg. 1950	1606	1581	1126	1294	1013	1025

* Average yield of duplicate plots.
† Land with 2 per cent slope.
‡ Land with 9 per cent slope.

twice at the Houston experimental site near Beaumont. Certain tillage plots received 30 pounds of nitrogen for barley one year previous to volunteer barley growth. Yields of these plots were compared with those where no fertilizer had been applied. No differences in the plant population of volunteer barley on these plots were observed. In both 1951 and 1957, differences in the average barley grain yield did not exceed 50 pounds per acre, indicating negligible differences in the amount of seed available as a source for the volunteer crop.

The effect of the primary tillage method used to kill the volunteer barley two years previously was reflected in the current production (table 15). Much higher yields were obtained with plowing than with disking or subtilling. The latter two methods did not differ greatly. Residual nitrogen increased production with all tillage methods. The increase of about 800 pounds per acre for nitrogen with disking and subtilling was 60 per cent greater than for the nitrogen treatment on the plowed plots.

Soil Nitrification

The low organic matter content of dryland soils and the possible effect of different tillage methods on nitrogen availability suggested the need for knowing the amount of nitrates in the soil in tillage experiments. Data obtained over a nine-year period showed that more soil nitrates accumulated over the fallow period where plowing (the most intensive tillage method) had been used (table 16). In certain years and at certain locations, differences were marked with increases up to 80 per cent for plowing. Usually, disking and subtilling were similar in their effect on nitrification.

A more comprehensive comparison of tillage methods with regard to nitrification was made on Arlington sandy loam at Riverside. Early fallow tillage operations, as well as intensive tillage methods, increased nitrate accumulation over the fallow period (table 17). In certain years, fall and winter tillages were conducive to high nitrate production. Midwinter disking was comparable or better than spring plowing three of four years. Of the nine tillage methods compared, midwinter disking and spring plowing resulted in higher amounts of soil nitrates in the 0- to 6-inch depth. In 1952, under conditions of favorable nitrification, disking was superior to less intensive methods, i.e., subtilling, rodweeding, and chiseling. In other years, it was similar to these methods. Average nitrate amounts show nontillage to be comparable to the less intensive tillage methods.

Soil samples were taken after crop harvest for nitrate determination in the Riverside experiment. Instead of the relatively constant level expected for

different tillage methods, it was found that nitrates were highest where more intensive tillage had been performed over a year previous to soil analysis (table 18). Particularly in 1951 and 1953, when appreciable nitrates were present in the soil after harvest, marked increases in nitrates were found with midwinter disking, spring disking, and for two types of spring plowing. Highest nitrates were found in plowed plots, generally 100 per cent greater than in nontillage and other less intensive tillage plots.

Reduction of Surface Crop Residue

Control of runoff, water erosion, and wind erosion by crop residues is proportional to the amounts remaining on the surface after tillage. The reduction in surface crop residue by different tillage methods was measured over the 1950–51 fallow period. Surface residues were weighed (a) at grain harvest in 1950, (b) in March 1951 just prior to tillage, and (c) prior to planting the grain crop in the fall of 1951. The rodweeder was used for secondary tillage operations on all plots.

Volunteer barley growth had increased the cover by the time tillage operations were initiated but contributed little to the weight of residue samples. Moldboard plowing immediately reduced surface residue by burying it (table 19). Less than 10 per cent of the crop residue remained on the surface six months after tillage. The disk and chisel were intermediate in residue reduction, with 54 and 62 per cent, respectively. The chisel was operated to a depth of about 8 inches. Subsurface tillage left a major portion of the residue on the surface. More than 60 per cent of the cover before tillage remained six months later. In Idaho, where grain residue is frequently twice the amount produced in southern California, Siddoway *et al.* (1956) report approximately 80 per cent remaining on the surface at wheat drilling after subtillage in the spring.

Soil Moisture Storage

The effect of the primary fallow tillage method on moisture stored in the soil was evaluated by determining the soil moisture content to a depth of 3 feet at the end of the fallow season. Primary tillage was performed during the latter half of March or the first week in April. Data presented in table 20 show a marked tillage difference in only one of four years on a Placentia sandy loam soil; average tillage differences over the four-year period were not significant. Subsurface tillage resulted in markedly greater moisture storage in 1950 than either disking or plowing. The increases of 1.56 inches and 0.78 inch, respectively, were highly significant. Plowing conserved 0.78 inch more than disking. Grain yields with subtilling were slightly higher in 1951, but differences were not statistically significant (table 6).

Table 12. Effect of Fallow Tillage Method on Barley Straw Production,* Placentia Sandy Loam, Beaumont

Tillage	Crop year						Avg.
	1949	1951	1953	1955	1957	1959	
	pounds per acre						
Plow	407	718	746	817	581	848	686
Disk	358	490	674	554	1025	1062	694
Subtiller	396	478	576	580	862	1062	659

* Average of 2 plots per year.

Table 13. Effect of Fallow Tillage Method in March on Nitrogen Content of Barley Straw under Different Nitrogen Fertility Conditions, Houston Ranch, Beaumont

Year	Plow		Disk		Subtiller	
	Check	30 lb N/A	Check	30 lb N/A	Check	30 lb N/A
	per cent N					
1951	.79	1.16	.85	1.08	.72	.93
1953	.55	.69	.58	.81	.53	.62
1955	.61	.73	.45	.71	.43	.63
1957	.81	1.17	.39	.82	.40	.48
Avg.	.69	.94	.57	.86	.52	.67
Tillage avg.	.80		.68		.60	

Moisture losses were determined over the 1956 summer fallow period where different tillage methods had been used. At the end of the fallow rainfall season, a higher total moisture content was measured in plowed plots (table 21). By August 10, moisture content of the surface 2 feet had decreased to the same level with all tillage methods. Between 40 and 45 per cent of the moisture to 2 feet was lost in the nine-week summer period. The soil moisture content after cropping is included to show the estimated amount of nonavailable water held by the soil to the 2-foot depth. Moisture content of the surface soil at harvest can be assumed to be at or below the wilting percentage.

Data obtained at another location on Ramona sandy loam soil indicate that with more vegetative cover, provided by planting a winter crop for this purpose, subsurface tillage may be expected to conserve more moisture over the fallow period (table 22). Tillage method had no effect on soil moisture conserved where no cover crop was planted. The additional residue supplied by a vetch crop and left on the surface by subtillage apparently conserved an additional inch of moisture in the soil when compared with plowing and disking. Grain yields, however, did not reflect this soil moisture difference.

Nitrogen Content of Soil

Total nitrogen content of the soil was determined at the beginning and end of a nine-year period in one of the tillage experiments on Placentia sandy loam. The experiment had been in progress six years before the initial nitrogen determinations were made. After 15 years of alternate fallow-barley cropping, there was no difference in total nitrogen level in the soil with different tillage methods (table 23). Decreases in nitrogen content over the nine-year period were similar. McCalla and Army (1961) reported little change in nitrogen content for the 0- to 12-inch soil layer after 17 years of subtillage in Nebraska.

Discussion of Tillage Effects

Dryland production of small grain straw in California usually varies between 500 and 4,000 pounds per acre, with most production below 3,000 pounds. During the recent dry period, straw production in southern California has frequently been less than 2,000 pounds (tables 11 and 12). Moldboard plowing practically eliminates surface residues regardless of the original amount. Disking, used properly, and particularly subtilling, will leave about 50 to 60 per cent of the original residue on the surface. Up to a point, the control

Table 14. Effect of Time and Method of Early Fallow Tillage on Nitrogen Content of Barley Straw,* Houston Ranch, Beaumont

Year	Tillage†		
	Check	Fall chisel	Midwinter disk
	per cent N		
1951	.62	.57	.83
1953	.47	.45	.68
1955	.34	.32	.47
1957	.34	.38	.44
Avg.	.44	.43	.60

* Average of 3 replications.
† All plots were subtilled in April of the fallow year.

of runoff and erosion is proportional to the amount of surface residue, with smaller amounts being more effective against wind erosion than water erosion (Zingg and Whitfield, 1957). Under southern California dryland conditions, all of the grain residues that can be retained on the surface are likely to be effective against runoff and water erosion. When straw production drops below 1,000 pounds per acre, only limited protection even with subtillage can be expected.

Except for one season, there was little or no effect of tillage method on the amount of moisture stored in the soil over the fallow period. While there may have been some runoff control, usually a small part of the annual rainfall occurred in the spring after tillage had been performed. According to Harris (1963), stubble mulching is more likely to increase moisture storage under high-intensity rainfall or when several days of continuous precipitation occur. There was some indication that fall chiseling or subsoiling in the fallow year may improve moisture conditions in slowly permeable California soils.

Under dryland conditions which limited grain yields to approximately 1,000 pounds per acre or less, plowing, disking, and subtilling were comparable. As yield potential increased, usually with more moisture, decreased yields were obtained with subsurface tillage and other less intensive methods. In a good production year (1950) on Ramona sandy loam, stubble mulching and disking yielded 1,350 and 1,200 pounds less, respectively, than moldboard plowing. Brady (1960) has reported a tendency for subtilled land to yield less than one-way plowed land in more favorable years, and data summarized by Zingg and Whitfield (1957) show decreased yields with subtillage in the more humid areas of the West. These investigators also report the converse, i.e., increases in yield with sub-

Table 15. Effect of Spring Tillage* and Nitrogen Fertility† on Volunteer Barley Production Two Years Later, Placentia Sandy Loam, Houston Ranch, Beaumont

Year‡	Volunteer barley forage yield (air-dry)					
	Plow		Disk		Subtiller	
	Check	30 lb N/A	Check	30 lb N/A	Check	30 lb N/A
	pounds per acre					
1952	1300	1660	740	980	740	1120
1958	4200	4760	2780	4140	2560	3860
Avg.	2750	3210	1760	2560	1650	2490

* Tillage to kill volunteer barley two years previously.
† Nitrogen applied before planting barley crop.
‡ Experiment conducted from 1947 to 1959.

Table 16. EFFECT OF SPRING TILLAGE METHOD ON SOIL NITRATES AFTER FALLOW, NO_3–N IN 0–6″ DEPTH*

Soil	Year	Plow	Disk	Subtiller
		parts per million		
Ramona sandy loam	1949	23	13	13
	1951	12	12	11
Placentia sandy loam, No. 1	1949	19	13	9
	1951	13	10	12
Placentia sandy loam, No. 2	1948	15	10	9
	1952	20	19	13
	1954	9	8	5
	1956	15	10	14

* Duplicate analysis of a composite of 6 soil samples.

tillage are generally associated with drier years and semiarid areas. Yields recorded in southern California under low rainfall and semiarid conditions were slightly higher with subtillage than with plowing in some years at two locations (tables 4 and 6). These increases have not been statistically significant, however, and are relatively small compared to the yield decreases obtained in other years or at other locations (tables 4 and 5).

At Nephi, Utah, with annual rainfall of 12.6 inches, Bennett *et al.* (1954) also report distinctly lower yields with stubble mulch tillage. Grain yields with disking have usually been intermediate between plowing and subtilling. Under more favorable moisture, they have been closer to subtilling.

Data on crop yield, nitrogen uptake, and soil nitrates obtained here suggest that subtilling decreased available nitrogen for plants, as compared to plowing. When available nitrogen was insufficient, grain yields produced with subtillage were increased more with added nitrogen than were those with plowing (table 5). Protein content of the grain, nitrogen content of the straw, and straw production were reduced by subtilling (tables 10, 11, 12, and 13). These results frequently reflect reduced nitrogen availability. This was confirmed by soil analysis, which showed depressed nitrates with the stubble mulch system. Lower quantities of soil nitrates with subtilling have been reported elsewhere (Johnson, 1950; McCalla and Army, 1961; Zingg and Whitfield, 1957). In the Great Plains, however, this nitrate depression has not

Table 17. EFFECT OF TIME AND METHOD OF FALLOW TILLAGE ON THE AMOUNT OF SOIL NITRATES IN THE 0–6″ DEPTH PRIOR TO THE CROPPING SEASON, ARLINGTON SANDY LOAM, RIVERSIDE

Year	No tillage	Fall chisel	Mid-winter disking	Spring tillage					
				Chisel	Rod-weeder	Sub-tiller	Disk	Disk plow	Moldboard plow
	parts per million								
1951	20	9	22	10	11	9	9	17	19
1952	9	24	29	16	18	16	24	21	44
1953	8	3	11	4	4	6	4	5	6
1954	3	6	7	8	4	4	5	4	4
Avg.	10	10	17	10	9	9	10	12	18

Table 18. EFFECT OF FALLOW TILLAGE METHOD ON THE AMOUNT OF SOIL NITRATES IN THE 0–6″ DEPTH AFTER THE CROPPING SEASON, ARLINGTON SANDY LOAM,* RIVERSIDE

Year	No tillage	Fall chisel	Mid-winter disking	Spring tillage					
				Chisel	Rod-weeder	Sub-tiller	Disk	Disk plow	Moldboard plow
	NO_3–N, *parts per million*								
1951	10	14	17	12	15	12	21	23	23
1952	11	6	6	9	8	13	6	6	12
1953	10	10	18	4	12	5	18	23	37
1954	2	2	2	2	3	2	3	3	2
Avg.	8	8	11	7	10	8	12	14	18

* Determinations on a composite of 6 soil samples.

generally resulted in decreased yields. It has, in fact, been suggested as being responsible for increased yields. In more humid areas, nitrogen has been required on subtilled land for yields comparable with plowing. Moisture supply and the nitrogen-supplying capacity of the soil are both involved in these subtillage effects. With the low levels of nitrogen in California dryland soils, relatively small amounts of moisture determine whether applied nitrogen will increase yields on subtilled land. Limited data indicate that under dry conditions the depressing effect of subtillage on nitrate production may be evident in vegetative growth from one to two years after the tillage operation.

Lower nitrification with subtilling than with plowing could result from differences in soil temperature, soil aeration, or distribution of crop residues in the surface soil. A review of stubble mulch research (McCalla and Army, 1961) indicates lower soil temperatures under a mulch, particularly in the spring of the year. Reported effects of mulch tillage on soil porosity are not consistent. Since depth of subtilling is usually less than that of plowing and because plowing shatters the surface soil more, better aeration with plowing seems likely. The effect of slowly decomposing surface residues, as compared to the more rapid decomposition of residue which has been incorporated and mixed with the surface

Table 19. REDUCTION IN SURFACE RESIDUE WITH DIFFERENT TILLAGE METHODS, HASKELL RANCH, BEAUMONT

Primary tillage*	Straw residue at harvest 7–28–50	Before tillage: Straw plus volunteer barley 3–14–51	After tillage: Residue 8–20–51	Residue reduction
	lb/A	lb/A	lb/A	*per cent*
Plow†	1590	2140	180	92
Disk†	1210	1670	770	54
Subtiller†	1020	1420	870	39
Chisel‡	1390	1670	740	62

* Primary tillage operation, March 21, 1951; two secondary operations with rodweeder, May 7 and July 6.
† Average of 40 ¼-milacre samples.
‡ Average of 30 ¼-milacre samples.

soil, is apparent in microbial activity and possibly seedling growth (McCalla and Army, 1961).

A greater need for the application of nitrogen fertilizer with subtillage and other less intensive tillage practices is clear from our work. The low level of nitrogen availability in California soils makes this an important factor in consideration of dryland tillage practices. On most soils and in areas of 15 to 20 inches of annual rainfall, nitrogen application is recommended where subtillage is used. The required application rate would vary with fertilizer placement, but probably should not be less than 30 pounds of nitrogen per acre. On soils with a low moisture-holding capacity and in areas of less than 12 inches of average annual rainfall, nitrogen fertilizer will be of limited value for grain production even where subtillage is used. The need for nitrogen under more intensive tillage, such as moldboard plowing and heavy disking, is more dependent on seasonal weather conditions. Local field trials with nitrogen should be considered in the higher rainfall areas.

Table 20. Moisture Conserved* in 3-Foot Depth of Soil by Late Winter Fallow With Different Fallow Tillage Methods,† Placentia Sandy Loam, Beaumont

Year	Plowing	Disking	Sub-tilling	Avg.
	inches			
1948	1.35	2.08	1.45	1.63
1950‡	1.24	0.46	2.02	1.24
1952	2.43	2.32	2.69	2.48
1954	2.42	2.76	2.59	2.59
Avg.	1.86	1.91	2.19	1.99

* Available moisture (excess over soil moisture content at crop maturity the previous year).
† Average of 6 plots in 1948, 1950, and 1954; average of 2 plots in 1952.
‡ Increased moisture storage for subtilling was statistically significant at the 1 per cent level.

Table 21. Changes in Moisture Content in Surface 2 Feet of Fallow Soil During Dry Summer Period,* 1956, Placentia Sandy Loam, Beaumont

Tillage	Fallow season				After cropping July 1957
	June 6	June 28	July 19	August 10	
	inches				
Plowing	3.7	3.2	2.4	2.0	1.6
Disking	3.1	2.5	2.5	1.8	1.6
Subtilling	3.2	2.9	2.4	2.0	1.5

* Total moisture, average of 3 samples.

NITROGEN

Mineral soils in California and the Pacific Southwest generally are low in nitrogen content (Mehring, 1945). Analyses of several cropped soils at different dryland sites in southern California indicate that less than 0.10 per cent nitrogen is present in the 0- to 6-inch layer (table 24). Analyses of samples in 6-inch increments to a depth of 24 inches showed a decrease in nitrogen content with depth. Usually the greatest decrease occurred in the 6- to 12-inch sample, although this decrease was less than for soils in more humid climates. Soils in other major dryland cropping areas of the United States, such as the Great Plains and the Palouse area of the Pacific Northwest, contain 3 to 6 times the amount of nitrogen found in most California dryland soils.

Table 22. Soil Moisture to 3-Foot Depth at Grain Planting With a Previous Cover Crop and Different Tillage Methods, Ramona Sandy Loam, Haskell Ranch, Beaumont, 1947

	Plowing	Disking	Subtilling
	inches		
Check*	2.00	2.09	2.13
Purple vetch cover crop	1.65	1.75	2.68

* Volunteer barley.

Cropping soils decreases the nitrogen content, usually rapidly at first and then more slowly as an apparent equilibrium is reached (Haas *et al.*, 1957). Data obtained at the beginning and end of a nine-year period for a Placentia sandy loam, cropped in an alternate fallow and barley system (table 23), showed decreases of 0.01 per cent nitrogen for the surface 2 feet of soil. From comprehensive studies elsewhere (Bracken and Greaves, 1940; Haas *et al.*, 1957; Hobbs and Brown, 1957), it seems doubtful that nitrogen content is steadily declining at this rate after 75 years of cropping. Lower than normal production and the concomitant return of less crop residue may have resulted in a greater temporary decline in organic matter and nitrogen over this nine-year period.

Frequency and Magnitude of Grain Yield Response

Replicated fertilizer experiments with nitrogen were conducted every year for the 15-year period, 1946–60. The number of experiments per year varied from one to four, and the plot size from .05 to .5 acre. With only a few exceptions, experimental sites were in western Riverside County. An assessment of response from 30 to 40 pounds of nitrogen per acre in the 32 experiments is shown in table 25. Yield increases of more than 200 pounds were measured in one-third of the experiments. No measurable response of grain yield to added nitrogen occurred in 10 of the experiments. In seven tests, the average yield increase was between 100 and 200 pounds. Nitrogen decreased yield in four of the experiments.

Statistical analyses of data from these field experiments with small grains showed that yield increases of over 200 pounds were usually significant at the 5 per cent level of probability. Increases ranging between 100 to 200 pounds were not always statistically significant, especially when only 2 or 3 replications were employed.

The lower average rainfall over the 1946–60 period (approximately 80 per cent) probably decreased the potential

Table 23. Total Soil Nitrogen with Different Tillage Methods* Over a 9-Year Period,† Placentia Sandy Loam, Beaumont

Soil depth	Plow		Disk		Subtiller	
	8/51	5/60	8/51	5/60	8/51	5/60
inches	*per cent*					
0–6	.055	.047	.056	.049	.062	.050
6–12	.057	.044	.052	.045	.057	.044
12–18	.053	.042	.048	.043	.055	.043
18–24	.055	.037	046	.039	.048	.040
Avg.	.055	.042	.050	.044	.056	.044

* Tillage performed during alternate or fallow year beginning in 1946.
† Average of 6 plots, including 2 each vetch cover crop and 30-pound nitrogen treatments. Neither treatment had any measurable effect on total nitrogen at time of sampling.

for positive response to nitrogen. Two important conclusions from this long-time study are that the practice of fallowing does not, in many cases, assure sufficient available nitrogen for the crop; and that yield decreases of dryland small grain can result from the application of nitrogen.

Available moisture can be expected to be a factor in determining response of dryland crops to applied nitrogen. However, because of relatively small differences in rainfall among different locations in any one year, moisture could account for only a part of the variable response to nitrogen. Available soil moisture and soil nitrates were determined just prior to planting in several field fertilizer experiments conducted during the 1959–60 season. Soil samples were taken to a depth of 6 feet, and moisture was determined gravimetrically. Separate samples were taken for bulk density and wilting point determinations. Subsequent rainfall was recorded at the experimental sites. Soil nitrates in the 0- to 6-inch depth were determined by the phenoldisulfonic method. Data in table 26 show that, depending on moisture conditions and soil nitrate content of the soil, grain yields may increase, decrease, or remain the

Table 24. Nitrogen Content of Several Dry-Farmed Soils in Southern California (0–6″ depth)

Soil type	Location	Average* per cent N
Greenfield sandy loam	Murrieta	.05
Ramona sandy loam	Beaumont	.05
Ramona sandy loam	Murrieta	.04
Placentia sandy loam	Riverside	.07
Placentia sandy loam	Beaumont	.06
Cajalco† fine sandy loam	Murrieta	.06
Perris† sandy loam	Murrieta	.04
Arlington† sandy loam	Riverside	.06
San Timoteo† very fine sandy loam	Murrieta	.05

* Average of 6 to 10 samples.
† Tentative soil series.

Table 25. Effect of 30 to 40 Pounds of Nitrogen per Acre on Small Grain Yields after Fallow in Southern California*

Year	Number of field experiments				
	Total	No response	Yield increase 100–200 lb	Yield increase >200 lb	Yield decrease 100–250 lb
1946	1			1	
1947	1	1			
1948	1			1	
1949	1	1			
1950	3	1	1		1
1951	1				1
1952	3			2	1
1953	3	2	1		
1954	3	1		2	
1955	1	1			
1956	4	1	2	1	
1957	2		1	1	
1958	2			2	
1959	2	1	1		
1960	4	1	1	1	1
Total	32	10	7	11	4

* Yields were average of 2 to 4 replications.

Table 26. Barley Yield Response to Applied Nitrogen under Different Moisture Conditions, Western Riverside County, 1960

Location	Available* soil moisture at planting	Rainfall after planting	Soil NO_3–N in 0–6″ depth at planting	Barley yield†	
				Check	30 lb N/A
	inches	*inches*	*lb/A*	*lb/A*	*lb/A*
Dysart Ranch	6.2	6.3	22	1440	1210
Christensen Ranch	1.0	2.0	4	290	290
McSweeney Ranch	3.4	3.3	6	350	460
Thompson Ranch‡	7.0	4.9	8	1060	1600

* Moisture in excess of that held at 15 atmospheres tension.
† Average of 3 replications.
‡ Wheat.

same when nitrogen is applied. Unfavorable rainfall distribution toward the end of the growing season produced some drouth stress at all locations. Phosphate was applied at all locations and had no effect on grain yield.

At the Dysart Ranch, with favorable moisture until heading and initially high soil nitrates, added nitrogen resulted in a significant yield decrease of 230 pounds per acre. A severe lack of moisture throughout the growing season at the Christensen Ranch precluded any nitrogen effect. With initially low soil nitrates and relatively moderate moisture, applied nitrogen increased average barley yield 110 pounds per acre at the McSweeney Ranch. This increase was significant at the 5 per cent probability level. Greatest positive response from nitrogen occurred where soil nitrates were low at planting and soil moisture was favorable. Under these conditions at the Thompson Ranch, a highly significant increase of 540 pounds of wheat per acre was obtained.

Moisture stress from heading to harvest was evident in the Dysart experiment. A shriveled appearance of the grain and an average test weight of 41 pounds per bushel verified this condition. Test weights of grain and straw yields were similar for all treatments. It is suggested that the excess of available nitrogen (provided by fertilizing) increased early growth to such an extent that mois-

Table 27. Effect of Rate of Nitrogen Application on Grain Yields in the Alternate Fallow—Grain Cropping System,* Western Riverside County

Year	Location	Grain yields			
		Check	15–20 lb N/A	30–40 lb N/A	60–80 lb N/A
		pounds per acre			
1950	Experiment Station, Riverside	710	....	590	530
1952	Experiment Station, Riverside	1500	....	1360	2020
1953	Experiment Station, Riverside	880	....	550	630
1954	Experiment Station, Riverside	1040	....	1300	1170
	Yoder Ranch, Murrieta	1030	....	1709	717
1956	Flynn Ranch, Wildomar	1040	1041	1091	1027
	Flynn Ranch, Wildomar	770	760	930	870
1960	Dysart Ranch, Banning	1220	1250	1040	980
	McSweeney Ranch, Hemet	460	490	440	430
	Thompson Ranch, Murrieta	980	1190	1440	1940

* Average yield from 3 or 4 replications.

Table 28. Comparison of Nitrogen Carriers at 30 Pounds of Nitrogen per Acre for Barley Production at Six Locations in Western Riverside County*

Year	Barley yields					
	Check	$(NH_4)_2SO_4$	NH_4NO_3	$Ca(NO_3)_2$	$CO(NH_2)_2$	NH_3
	pounds per acre					
1952	1100	1600	1600	1680	....	....
1954	940	1240	....	....	....	1480
1954	1420	1440	1550	1540	1330	1400
1954	1030	1710	1700	1780	....	....
1956	630	810	850	760	....	....
1956	940	1230	1040	1380	....	....

* Average of 3 or 4 replications.

Table 29. EFFECT OF A 30- TO 40-POUND NITROGEN APPLICATION ON CRUDE PROTEIN CONTENT OF GRAIN*

Year	Location	Soil type	Crude protein†	
			Check	Nitrogen
			per cent	
1950	Beaumont	Ramona sandy loam	8.0	8.7
1950	Beaumont	Placentia sandy loam	6.8	7.2
1953‡	Beaumont	Placentia sandy loam	13.1	13.8
1954	Riverside	Placentia sandy loam	13.4	14.1
1954§	Murrieta	Placentia clay loam	9.4	9.8
1956§	Murrieta	Placentia clay loam	12.9	15.4
1956	Wildomar	Hanford sandy loam	9.9	15.9
1956	Murrieta	Las Posas‖ loam	11.9	12.7
1957‡	Beaumont	Placentia sandy loam	13.1	14.1
1959‡	Beaumont	Placentia sandy loam	11.2	12.7
Avg.			11.0	12.4

* Plow or disk tillage; ammonium sulfate or ammonium nitrate fertilizer; alternate fallow—crop system.
† Per cent nitrogen X 6.25.
‡ Same experimental site.
§ Same experimental site.
‖ Tentative soil series.

ture use was increased and the subsequent exhaustion of soil moisture occurred first in the fertilized plots.

Rate of Application

Nitrogen application rates were compared in ten field experiments from 1950 to 1960, inclusive. Rates ranged from 15 to 80 pounds per acre. The method of application usually consisted of broadcasting, followed by shallow disking before planting.

Only in one of five experiments was a marked yield increase obtained from a rate in the 15- to 20-pound range (table 27). Rates between 30 to 40 pounds per acre increased yields in 4 of 10 experiments. Significantly greater yield increases from 60 to 80 pounds of nitrogen per acre occurred in two of the experiments. In three experiments, significant decreases in yield were caused by application of these relatively high rates of nitrogen. Where nitrogen is broadcast for dryland grain production with the alternate fallow-crop system, rates of from 30 to 40 pounds per acre are probably near optimum on southern California soils.

Preliminary studies with nitrogen placement for dryland grain indicate that placement with the seed at planting or below the seed row results in slightly more efficient use than does broadcasting before drilling or after emergence. Placing more than 30 pounds of nitrogen (as ammonium nitrate or urea) with the seed is hazardous under dryland conditions because of frequently observed decreases in emergence of the crop.

Fertilizer Sources

The following nitrogen fertilizers at 30 pounds of nitrogen per acre were

Table 30. EFFECT OF APPLIED NITROGEN ON BARLEY STRAW PRODUCTION, ARLINGTON SANDY LOAM, RIVERSIDE

Year	Rainfall	Nitrogen applied (lb/A)		
		None	40	80
	inches	*pounds per acre*		
1952	17.47	1609	1969	3188
1953	9.58	1766	1453	1906
1954	11.56	1641	2516	3328
Avg.	12.87	1672	1979	2807

compared at several locations: ammonium sulfate, ammonium nitrate, calcium nitrate, urea, and ammonia. The source of nitrogen applied usually either had little or no effect on barley grain yield (table 28). In one of the 1954 experiments where nitrogen markedly increased yield, ammonia was clearly superior to ammonium sulfate.

Grain Quality

Crude protein content is a criterion for quality of feed grains such as barley. Inasmuch as it is determined by the nitrogen content of the grain, nitrogen fertilizer may be expected to affect the level present. Thirty to forty pounds of nitrogen per acre increased the average crude protein content of barley grain 1.4 per cent in ten field experiments (table 29). Increases in individual experiments ranged from less than 1 to 6 per cent. Both the soil type and the growing season had a marked effect on the level of crude protein in the grain. The largest increase with nitrogen occurred on the Hanford sandy loam soil.

Test weight, a universal criterion for quality in the marketing of grains, was determined in several experiments. Except in a few instances, the application of 30 or 40 pounds of nitrogen per acre did not significantly affect test weight of the grain. In one experiment, 30 pounds of nitrogen significantly decreased test weight 2.6 pounds per bushel. Similar trends were noted in other experiments, but differences were small and not statistically significant.

Straw Yield

When needed, relatively low rates of nitrogen have previously been shown in this report to be optimum for dryland grain production. Increasing the rate to 80 pounds per acre usually either increased yield very little or not at all and, in some cases, resulted in decreases. Higher rates of nitrogen, however, frequently produced marked additional increases in straw yield (table 30). In two of three seasons at Riverside, 80 pounds of nitrogen doubled straw yields and markedly increased yields over those obtained with 40 pounds every year. These results confirm many observations of increased vegetative growth with added nitrogen.

Data presented in table 25 show no grain yield response to applied nitrogen in about one-third of the experiments over a period of lower-than-average rainfall. Straw yields, however, were increased in several of these experiments (table 31). Consistent and frequently large increases in straw production were obtained with 30 or 40 pounds of nitrogen even though grain yields were decreased or not appreciably affected. Straw increases ranged from 370 to 780 pounds per acre. The supply of moisture in the latter part of the growing season fre-

Table 31. Grain and Straw Production With Applied Nitrogen Under Limiting Moisture, Western Riverside County

Location	Year	Grain yield		Straw yield	
		Check	30–40 lb N/A	Check	30–40 lb N/A
		pounds per acre			
Experiment Station, Riverside	1952	1500	1360	1600	1970
Experiment Station, Riverside	1954	1420	1440	1810	2500
Yoder Ranch	1956	630	810	790	1230
Flynn Ranch	1956	1040	1110	1560	2340
McSweeney Ranch	1960	410	470	810	1320

quently limits grain yield and a positive response to nitrogen.

Residual Effect

Under the variable and deficient moisture supply encountered with dryland farming, it is reasonable to expect incomplete use of nitrogen fertilizer applied to the soil. Nitrogen not removed from the soil by the crop could remain in the root zone, be leached from the root zone, and/or be volatilized and lost to the atmosphere. Under conditions of low effective rainfall, as in the Pacific Southwest, leaching would likely be less of a factor than in high-rainfall areas.

In two experiments near Beaumont, the volunteer barley forage production was measured the year following fertilization with 30 pounds of nitrogen for the grain crop. A marked residual effect was noted in every case (table 32). Forage yields were increased as much as 1,000 pounds per acre by the residual effect of this relatively low rate of applied nitrogen.

Continuous annual grain cropping, practiced in one experiment, revealed a residual effect of nitrogen on grain yield. A 60 per cent yield increase was obtained from the residual effect of 40 pounds of nitrogen applied the previous year, compared to a 90 per cent increase for the same rate applied the season of measurement.

Response to Applied Phosphorus

Fourteen field experiments conducted in western Riverside County between 1950 and 1963 included the application of phosphate fertilizer alone and with nitrogen. In only two of these experiments did the application of phosphate increase grain yields. The phosphate was applied with nitrogen and the yield increase over the average of the nitrogen plots was from 200 to 400 pounds of grain per acre. Phosphorus alone had no effect on yield.

Table 32. Residual Effect of Nitrogen Fertilizer on Annual Forage* Production, Western Riverside County

Location	Year	Forage yield	
		Check	30 lb N/A applied previous year
		pounds per acre	
Haskell Ranch, No. 1	1951	1570	1880
Haskell Ranch, No. 2	1951	1730	1800
Houston Ranch......	1952	920	1250
Houston Ranch......	1956	770	1720
Houston Ranch......	1958	3180	4250

* Volunteer barley; air-dry weights.

Legume Cover Crops

A legume cover crop alternating with grain not only should provide adequate protection for the soil surface, but also should (if turned under as a green manure crop) increase the available nitrogen for the subsequent grain crop. A purple vetch cover crop was compared to the application of 30 pounds of nitrogen for the grain crop. Considerable data over an 11-year period show that the nitrogen application produced the highest yields in the majority of comparisons (table 33). Only in one case on the higher-producing Placentia soil was vetch markedly better than 30 pounds of nitrogen. At the Ramona site, yield increases from fertilizer over vetch cropping were statistically significant. Differences on the lower-producing Placentia soil where nitrogen was not limiting were small and usually not significant.

Two of the best adapted winter legumes for dryland cropping when this work was initiated were purple vetch and blue lupine. Each of these legumes was grown in alternate years with barley over an eight-year period on a Ramona sandy loam soil. Volunteer barley was permitted to grow on check plots. All cover crop growth was killed between March 15 and April 7. No significant difference between legumes was measured in the yield of the

following barley crop (table 34). Legume cover cropping did result in small but consistently higher barley yields than volunteer barley.

As previously stated, a cover cropping with legumes has the added advantage of increasing the nitrogen supply in the soil. A major part of this increase results from returning the crop to the soil. Amounts of nitrogen in above-ground parts of several cover crops are shown in table 35. As expected, the legume vegetation contained more nitrogen than the barley. From 5 to 35 pounds more nitrogen per acre were contained in the purple vetch and blue lupine crops.

Dryland Crop Response To Nitrogen

Fallowing land increases the accumulation of soil nitrates between crops. Under dryland conditions in California soils, however, the total supply of available nitrogen after fallow is not always adequate for grain production. Grain yields were increased by nitrogen application in one-half of the field experiments conducted in southern California over a 15-year period of below-normal rainfall. Martin and Mikkelsen (1960) report positive response to nitrogen in 49 per cent of their nonirrigated grain tests, the majority of which were in central and northern California. Widespread response of wheat to nitrogen after fallow on dryland areas of Utah has been shown by Peterson (1952). These results contrast with those obtained in the Great Plains, where fallow grain crops have not generally responded to nitrogen (Staple, 1960). With much higher nitrogen contents, Great Plains soils apparently provide sufficient available nitrogen after fallow.

Under dryland conditions, application of nitrogen fertilizer without regard to

Table 33. Comparison of the Effect of 30 Pounds of Nitrogen per Acre and a Vetch Cover Crop on Barley Yield,* Beaumont

Soil	Year	Barley yield		
		Check†	Nitrogen fertilizer†	Vetch
		pounds per acre		
Ramona sandy loam‡....	1948	1236	1646	1393
	1950	2424	3004	2746
	1952	900	1456	1256
Avg..................		1523	2035	1798
Placentia sandy loam‡...	1948	1018	1420	1528
	1950	2337	2580	3256
	1952	935	1344	1096
Avg..................		1430	1781	1960
Placentia sandy loam§...	1949	516	446	556
	1951	887	699	889
	1953	996	1014	725
	1955	1356	1354	1260
	1957	380	492	304
	1959	1320	1256	1140
Avg..................		909	877	812

* Ammonium sulfate fertilizer applied before planting grain crop; purple vetch planted in alternate years with grain crop; heavy disking was primary tillage method.
† Volunteer barley crop.
‡ Haskell Ranch.
§ Houston Ranch.

Table 34. EFFECT OF DIFFERENT COVER CROPS ON SUBSEQUENT BARLEY YIELDS, RAMONA SANDY LOAM SOIL, BEAUMONT

Cover crop	Barley yields*				
	1953	1955	1957	1959	Avg.
	pounds per acre				
Volunteer barley	1000	1060	560	1330	980
Purple vetch	1110	1220	590	1560	1120
Blue lupine	1070	1310	700	1650	1180

* Average of 4 replications.

the available moisture supply or the capacity of the soil to make nitrogen available may result in no response or a decreased grain yield. Grain crops frequently show a vegetative color and growth response to added nitrogen. Straw yields reflect this increased vegetative growth. If rainfall is deficient in the spring and the stored soil moisture is exhausted before the grain crop matures, either no response or a decrease in grain yield may result. Ramig and Rhoades (1963) found that when available moisture was low, nitrogen increased straw more than grain production. Under seriously limiting moisture conditions in Oregon, Hunter and co-workers (1961) reduced wheat yields by applying relatively low rates of nitrogen. Fall applications were more effective in reducing yields. The evidence suggests that decreases in dryland wheat yields from applied nitrogen result from earlier exhaustion of available moisture, which may be caused by additional early growth, and/or generally taller and more luxuriant vegetative growth throughout the season. A higher probability for response of dryland grain crops to nitrogen undoubtedly could be achieved by considering the amount of available moisture in the soil; time of application with respect to the current rainfall season; and amount of soil nitrates or the nitrifying capacity of the soil.

An application of nitrogen appears to be required for dryland grain in southern California before a response to phosphate fertilizer will be obtained. The limited response to phosphorus indicates an adequate supply in several of the soils studied under the prevailing low moisture conditions.

Marked positive residual effect of nitrogen fertilizer on forage production the year following a grain crop indicates that under a fallow-grain-annual pasture cropping system there is some compensation

Table 35. NITROGEN CONTENT OF DIFFERENT LEGUMINOUS COVER CROPS, WESTERN RIVERSIDE COUNTY*

Location	Year	Cover crops					
		Volunteer barley	Purple vetch	Blue lupine	Bur clover	Bitter clover	Bicolor lupine
		pounds nitrogen per acre					
Murrieta	1953	19.7	25.5	27.0	....	21.2	....
Sunnymead	1953	....	29.3	18.2	....	....	....
Murrieta	1954	15.9	40.2	51.3	32.1	....	31.8
Beaumont	1956	12.2	17.6	27.8	....	....	....

* Average of a minimum of seven ¼-milacre samples per plot taken in late March or early April.

for low efficiency of nitrogen use on grain in dry years.

Legume cover crops, such as purple vetch and blue lupine, increase the nitrogen content of the soil for a short period after they are incorporated. Under low rainfall in southern California, the amount of nitrogen in the tops of these legumes frequently has not exceeded 50 pounds per acre. Both purple vetch as a cover crop and 30 pounds of nitrogen as ammonium sulfate increased barley yields significantly. Higher yields were more frequently obtained with the fertilizer. In the low rainfall areas for dryland cropping, annual legumes frequently are not a dependable source of nitrogen. Deficient rainfall in the fall or early winter prevents emergence and results in limited growth. A cover crop cannot be permitted to grow beyond the early spring months because depletion of stored soil moisture probably will decrease the subsequent grain yield.

Judicious use of nitrogen fertilizer can undoubtedly increase the efficiency of moisture use in dryland grain production. Recommendations for a nitrogen fertilization program are complicated because of the variability in moisture supply, both within and between cropping seasons. Consideration can be given to nitrogen application when the crop is in the seedling stage if more moisture suddenly becomes available.

Results reported here indicate that rates in excess of 40 pounds of nitrogen per acre are rarely justified in southern California. This is in agreement with the findings of Martin and Mikkelsen (1960) for other areas of the State.

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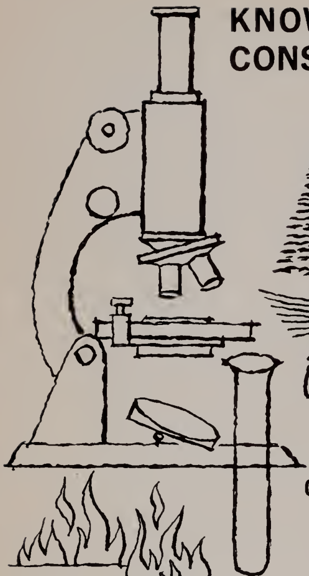

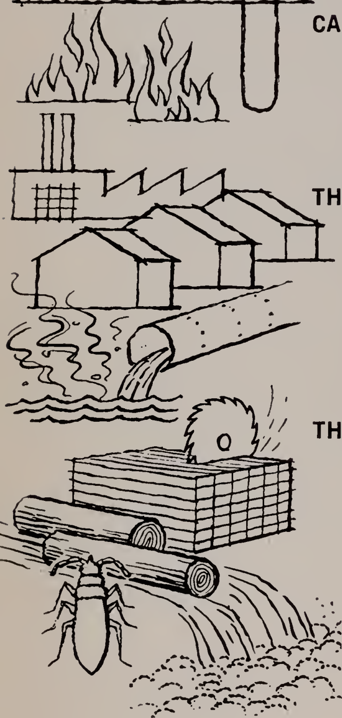

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